



## STATE & PRIVATE FORESTRY FOREST HEALTH PROTECTION SOUTH SIERRA SHARED SERVICE AREA



**Report Number:** SS11-05

**Title:** Assessment of Duff and Litter Depth and Raking to Protect Large-Diameter Pines near Upper Cow Creek, Summit Ranger District, Stanislaus National Forest

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### *Report Highlights*

- Case study quantifies high duff and litter fuel depths surrounding 121 large-diameter pines and preliminary results support raking to reduce fire injury and protect high-value trees
- No tree mortality or other evidence was observed one year post-raking to indicate raking treatments can directly cause large-diameter pine mortality
- Depth to mineral soil (duff + litter depth) was greater in ponderosa (mean 20 cm, range 10-31 cm) compared to sugar pines (mean 15 cm, range 7-31 cm) and increased with increasing tree diameter in both species
- Depth to mineral soil was slightly greater ( $\approx 4$  cm) upslope compared to downslope for both ponderosa and sugar pines
- Maximum depth to mineral soil measurements ranged from 25-50 cm in 66% of study trees
- One year post-fire raked trees generally had no bark char or red turpentine beetle (RTB)-attack while non-raked trees generally had moderate char and 20% had RTB-attack
- An additional Upper Cow monitoring unit was established to monitor 168 large-diameter, spatially inter-mixed ponderosa and sugar pines exposed to Rx fire in Summer 2008
- One year post-burn in monitoring unit: RTBs attacked 45% of all sugar pines (mean 31 pitchtubes tree<sup>-1</sup>) and only 18% of all ponderosa pines (mean 18 pitchtubes tree<sup>-1</sup>)

An adaptive management case study was initiated in 2008 to assess duff and litter fuel depths adjacent to large-diameter pines and efficacy of raking to reduce tree injury and mortality with exposure to prescribed underburning. This project was facilitated through collaborative efforts between the Central Sierra Environmental Research Council (CSERC), the Stanislaus National Forest, and Forest Health Protection to enhance management decisions regarding large-diameter sugar and ponderosa pine health. A rake-only and rake + Rx fire study unit was established near Upper Cow creek in an area where fire had been excluded from the ecosystem for at least 100 years. Study trees consisted of 121 large-diameter sugar (*Pinus lambertiana*) or ponderosa pines (*Pinus ponderosa*) that averaged 40" diameter at 4.5 feet in height (DBH). Trees were raked by volunteers with the CSERC on 5/15/09 and Rx fire application occurred on 11/11/09. This report summarizes litter and duff depths surrounding study trees and one year post-burn observations.



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## **Introduction**

Prescribed (Rx) underburning is a widely used management tool for reducing hazardous surface and ground fuels where the historic fire regime has been altered. Fire exclusion can lead to fuel depths that exceed historic and natural ranges of variability (Covington et al., 1997). Exposure to fire can lead to direct tree mortality, tree injury, increased susceptibility to bark beetle attack, and/or delayed tree mortality. Probability of delayed conifer mortality has been correlated with fire damage severity and is often associated with bark beetle-attack (Appendix A).

Tree mortality of large-diameter pines following Rx fire application may conflict with management objectives. Delayed conifer mortality following bark beetle colonization of fire-injured trees has been documented in scientific literature (Appendix A) and within two miles of this study area in > 40" DBH ponderosa pines that were exposed to Rx fire in 2005 (Egan, 2009).

Raking the duff and litter adjacent to the bole of large diameter trees (Picture 1) has been identified as a viable tool to reduce fire-caused tree injury, tree mortality, and red turpentine beetle attack (Hood, 2010; Nesmith et al., 2010). Hood et al. (2007) demonstrated that raking reduced cambium injury and red turpentine beetle attack in raked ponderosa/Jeffrey pines in eastside pine stands of the northern Sierra-Nevada Mountains. Nesmith et al. (2010) concluded that raking sugar pines in Sequoia and Kings Canyon National Parks can effectively reduce moderate to large-diameter sugar pine mortality (>20" DBH) when average stand duff/litter depths exceeds 30 cm. Raking did not have a negative impact on treated trees in this study (Nesmith et al., 2010). See Hood (2010) for an in-depth review of large-diameter tree protection.

This project is a case-study to monitor raking treatments in the Upper Cow drainage that was identified for 2009 Rx fire treatment. Pre-burn data is presented to illustrate magnitude and distribution of duff and litter immediately adjacent to large-diameter (>30" DBH) pines.



**Picture 1. CSERC volunteer removing forest floor fuel adjacent to large-diameter sugar pine.**

Data from post-treatment monitoring will be used to assess tree injury (bark char severity proxy; Hood et al., 2008), beetle attack, and/or mortality for large-diameter raked and non-raked pines.

These monitoring efforts are beneficial as ground fuel loadings may exceed levels assessed in previous experimental studies and study location is within the Summit Ranger District which manages forests that often contain high-value pines >30" DBH. This project will serve as a local case study to facilitate adaptive management and improve decisions pertinent to large-diameter tree health.

## **Methodology**

Detailed methodology regarding study location determination and treatment populations of interest are provided in Appendix D. Two study locations that had majority of trees >30" DBH were established adjacent to Upper Cow Creek, Summit Ranger District, Stanislaus National Forest to have respective rake-only and rake + Rx fire treatments (Appendix B – Study Area Map). 30 pairs of study trees were selected in each study unit and each pair was randomly assigned a rake and a no-rake treatment. Duff and litter depth from surface layer were measured at three distances from bole locations in each of four quadrants (Figure 1); totaling  $\approx 2,900$  measurements. Raked trees had all duff and litter removed to a 2-foot radius around study trees with displaced fuels evenly distributed outward from raked locations. Raking treatments were completed by volunteers from the CSERC on 5/5/2009 and trees were re-raked on 10/3/2009 prior to Rx fire application on 11/11/2009.



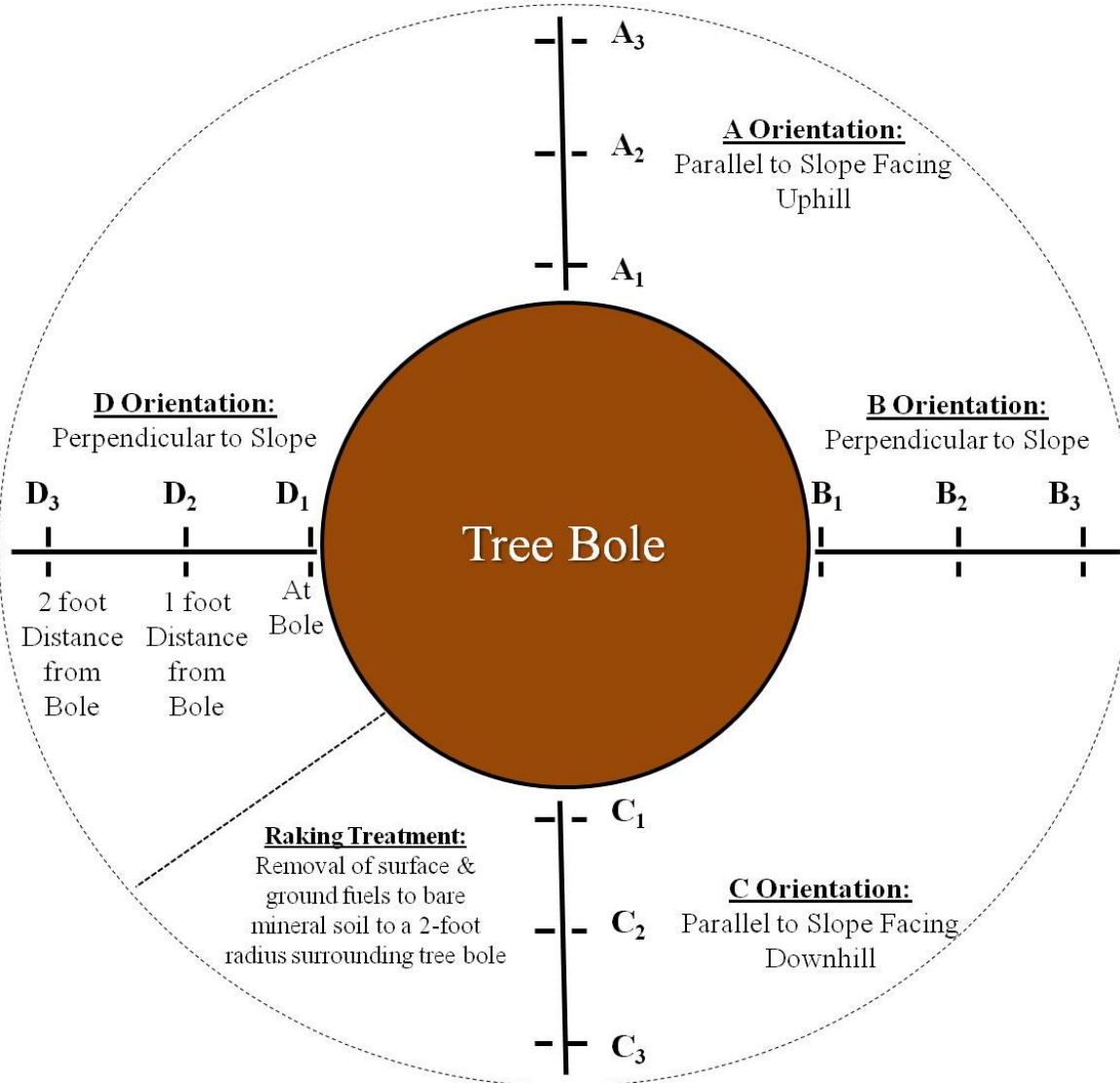
**Pictures 2 & 3. Depiction of pre and post-raking fuel distribution for sugar pine near Upper Cow Creek.**

## **Fuel Distribution Adjacent to Legacy Pines Prior to Treatment**

Fuel depth was assessed through analysis of covariance (ANCOVA) (SAS Institute Inc., 2004) to identify factors associated with total depth to mineral soil (duff + litter depth). Mean depth to mineral soil (averaged from the 12 measurement locations depicted in Figure 1) was utilized as the response variable in an ANCOVA model with study unit, tree species, and DBH incorporated as potential predictors. Variables were assessed for significance with Type III effects tests.

There was no difference in mean depth to mineral soil between two study units ( $F_{1,117} = 0.2, p = .634$ ) and greater fuel depth in ponderosa vs sugar pines ( $F_{1,117} = 28.7, p = .0035$ ); thus, descriptive statistics are combined from both units and presented by species (Tables 1 & 2). Mean depth to mineral soil increased with increasing diameters for both ponderosa and sugar pines ( $F_{1,117} = 18.2, p < .001$ ) (Figure 2). Average depth to mineral soil values ranged from 15–30 cm for majority (63%) of study trees.

**Figure 1. Schematic Diagram of Duff & Litter Fuel Depth Sampled Locations & Raking Treatment**



**Table 1. Sugar pine tree and ground fuel characteristics**

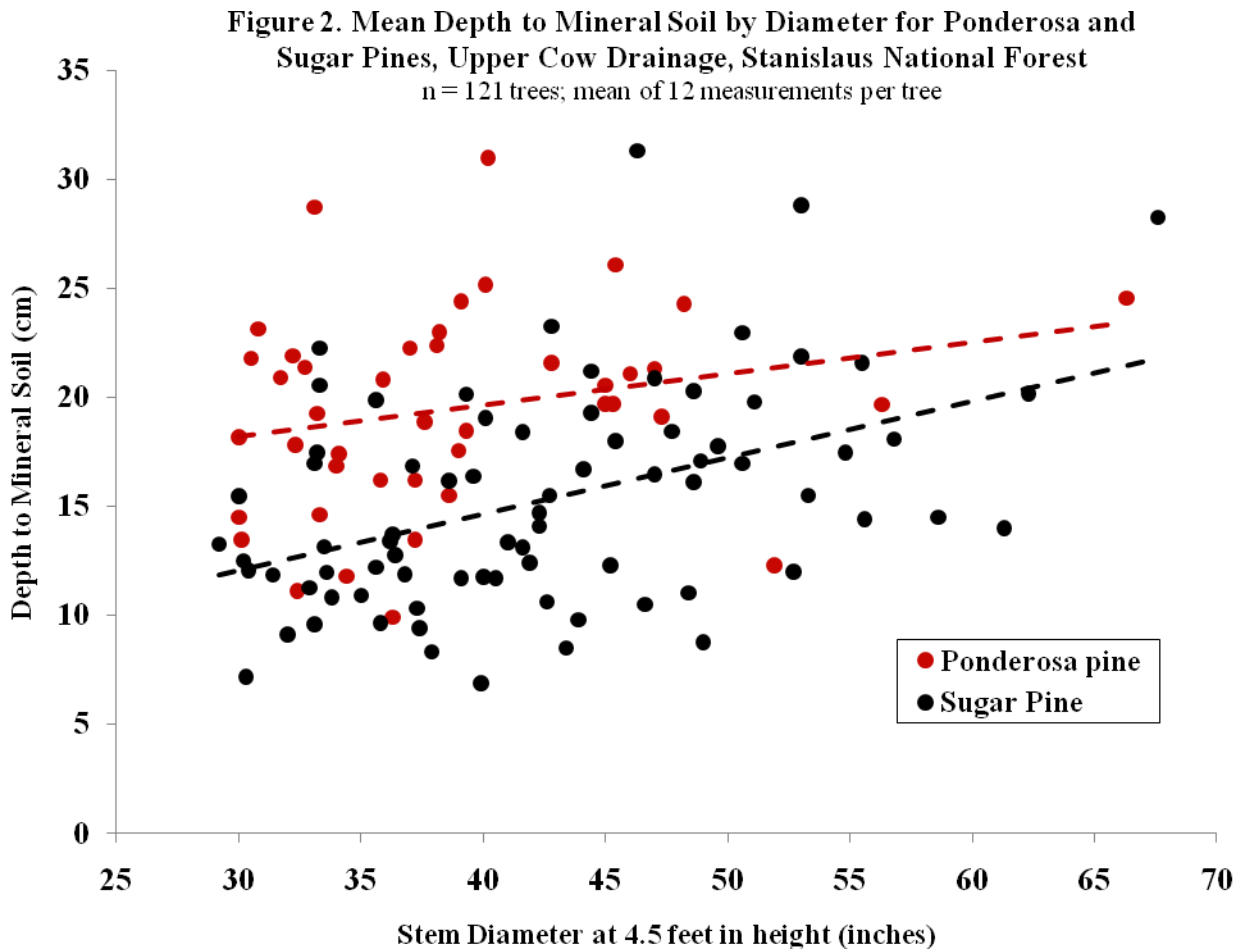
Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem DBH (in)	78	42.6	42.0	8.6	29.0	68.0
Litter Depth (cm)	78	7.8	7.6	2.8	3.1	18.0
Duff Depth (cm)	78	7.5	6.7	3.0	3.6	19.7
Depth to Mineral Soil (cm)	78	15.3	14.5	4.9	7.0	31.0

**Table 2. Ponderosa pine tree and ground fuel characteristics**

Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem DBH (in)	43	38.9	37.2	7.7	30.0	66.3
Litter Depth (cm)	43	10.0	9.7	2.9	4.9	17.5
Duff Depth (cm)	43	9.6	9.5	2.5	4.5	13.8
Depth to Mineral Soil (cm)	43	19.5	19.7	4.6	9.9	31.0

**Note:** Depth to mineral soil averaged from 12 measurements per tree indicated in Figure 1

Depth to mineral soil was averaged by location to describe characteristics based on sample orientation to topographic slope (Figure 1<sub>A-D</sub>) and distance from bole (Figure 1<sub>1-3</sub>) (Tables 3-6). Depths were greater uphill compared to downhill sample locations for both ponderosa and sugar pines as tested with paired-plot Wilcoxon signed rank test ( $p < .001$  for both species) (Hollander and Wolfe, 1973). Maximum sample depths were generally located in uphill orientation and ranged from 25-50 cm in majority (66%) of study trees (Figure 3). Sample locations perpendicular to slope were not compared statistically but appeared similar to uphill rather than downhill values (Tables 3 & 4). Sample locations based on distance from bole were not compared statistically but depth to mineral soil appeared constant (Tables 5 & 6).



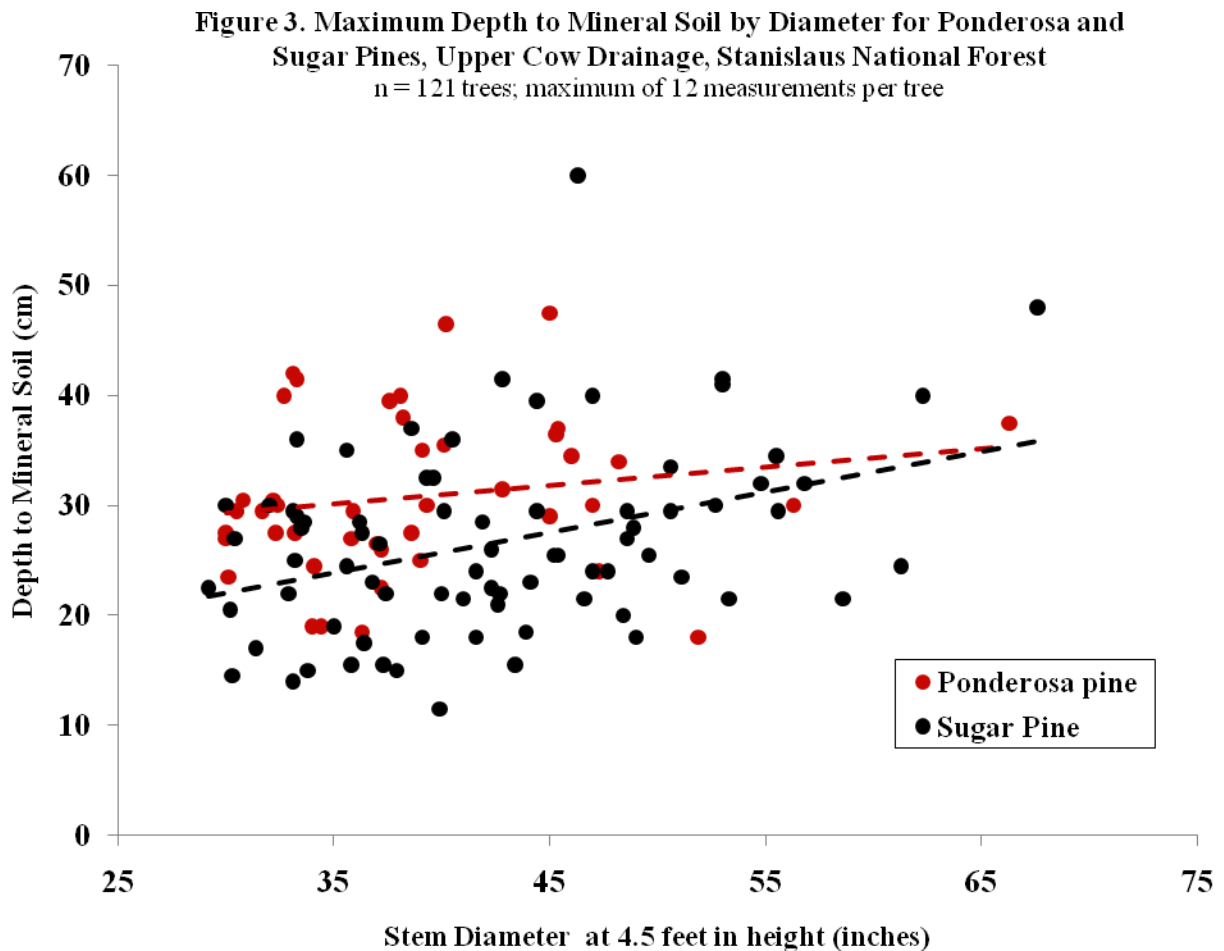
**Table 3. Sugar pine ground fuel depth to mineral soil (cm) by slope orientation**

Sample Location	n	Mean	Median	Std Dev	Minimum	Maximum
Upslope (A <sub>1-3</sub> )	78	17.2	16.4	8.2	0.0	54.5
Downslope (C <sub>1-3</sub> )	78	13.7	13.1	6.8	0.8	33.5
90 degree left (B <sub>1-3</sub> )	78	15.0	14.8	6.5	1.2	41.5
90 degree right (D <sub>1-3</sub> )	78	16.2	15.7	6.8	2.5	36.7

**Table 4. Ponderosa pine ground fuel depth to mineral soil (cm) by slope orientation**

Sample Location	n	Mean	Median	Std Dev	Minimum	Maximum
Upslope (A <sub>1-3</sub> )	43	20.8	20.7	6.4	10.2	40.3
Downslope (C <sub>1-3</sub> )	43	16.6	17.2	5.9	4.8	30.7
90 degree left (B <sub>1-3</sub> )	43	19.5	19.7	6.3	6.2	38.0
90 degree right (D <sub>1-3</sub> )	43	21.4	21.0	7.6	0.0	42.0

**Note:** Fuel depths averaged from 3 slope orientation locations per tree as indicated in Figure 1

**Table 5. Sugar pine fuel depth to mineral soil (cm) by distance from bole**

Sample Location	n	Mean	Median	Std Dev	Minimum	Maximum
At Bole (A-D <sub>1</sub> )	78	15.2	14.7	6.5	4.5	36.8
1' from Bole (A-D <sub>2</sub> )	78	14.8	14.1	5.3	6.5	31.9
2' from Bole (A-D <sub>3</sub> )	78	15.8	15.3	4.8	7.5	27.9

**Table 6. Ponderosa pine fuel depth to mineral soil (cm) by distance from bole**

<b>Sample Location</b>	<b>n</b>	<b>Mean</b>	<b>Median</b>	<b>Std Dev</b>	<b>Minimum</b>	<b>Maximum</b>
At Bole (A-D <sub>1</sub> )	43	19.2	19.8	5.5	7.3	30.6
1' from Bole (A-D <sub>2</sub> )	43	19.1	19.0	5.9	7.4	34.6
2' from Bole (A-D <sub>3</sub> )	43	20.0	19.1	3.8	13.3	32.1

**Note:** Fuel depths averaged from 4 bole distance locations per tree as indicated in Figure 1

### **One Year Post-Treatment Observations**

Study trees were assessed one year following raking and Rx burning treatments during the week of October 25<sup>th</sup>, 2010. The Rx fire application exposed all study trees to fire and was generally considered a mild burn as snowfall occurred within 1 week of fire application. Duff and litter consumption surrounding study trees was favorable and often ranged from ≈ 70-100%. Each study tree was surveyed for red turpentine beetle (*Dendroctonus valens* LeConte) (RTB), mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) and western pine beetle (*Dendroctonus brevicomis* LeConte) (WPB) attacks. Trees were also surveyed for bark char severity (Hood et al., 2008) and bark char height in each of four quadrants (A<sub>1</sub>-D<sub>1</sub>, see Figure 1).

In the rake-only unit (no Rx fire), study trees were 50% ponderosa and 50% sugar pine species that averaged 37.6" DBH (range 30-67" DBH). All trees were alive one year post-raking and none had RTB-attack. Two live, raked ponderosa pines (33 & 39" DBH) had evidence of WPB pitchtubes; however, inner-bark surveys were not conducted to assess beetle success to prevent confounding with tree mortality. Both trees had woodpecker damage prior to raking treatment.

In the rake + Rx fire unit, 80% of study trees were sugar pines and descriptive statistics are stratified by raking treatment rather than species (Tables 7 & 8). All trees were alive one year post-burn/raking treatment and raking treatments had a favorable effect on study trees to-date. Generally, raked study trees had no RTB attack or bark char while 20% of all non-raked trees had RTB attack and majority had moderate bark char (Picture 4). Basal char height was significantly greater in uphill slope orientation compared to downhill for trees with char as assessed with paired-plot Wilcoxon signed rank test ( $p < .001$ ) (Hollander and Wolfe, 1973). One live, raked ponderosa pine had evidence of WPB pitchtubes; however, inner-bark surveys were not conducted to assess beetle success to prevent confounding with tree mortality. This tree had an extensive basal area scar (catface) and oleoresin present prior to treatments.



**Picture 4. Example of raked and non-raked pines with active Rx underburning treatment. Note the difference in bark char with fuel raking treatment.**

**Table 7. Raked tree characteristics one year post-treatment in rake + Rx fire unit**

Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem Diameter (in)	30	45.1	45.4	7.5	35.6	62.3
Quadrants w/ Severe Char <sup>a</sup>	30	0.0	0.0	0.0	0.0	0.0
Mean Bark Char Height (ft)	30	0.0	0.0	0.2	0.0	1.2
Upslope Bark Char Height (ft)	30	0.0	0.0	0.1	0.0	0.3
Downslope Bark Char Height (ft)	30	0.0	0.0	0.0	0.0	0.0
RTB (tubes tree <sup>-1</sup> ) <sup>b</sup>	30	0.0	0.0	0.0	0.0	0.0
Pine Beetles (tubes tree <sup>-1</sup> ) <sup>b</sup>	1	10.0	10.0	n/a	10.0	10.0

**Table 8. Non-raked tree characteristics one year post-treatment in rake + Rx fire unit**

Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem Diameter (in)	30	45.0	44.4	8.4	29.2	66.3
Quadrants w/ Severe Char <sup>a</sup>	30	0.3	0.0	0.6	0.0	2.0
Mean Bark Char Height (ft)	30	1.3	0.5	1.7	0.0	6.5
Upslope Bark Char Height (ft)	30	2.0	0.8	3.1	0.0	11.3
Downslope Bark Char Height (ft)	30	0.5	0.2	1.2	0.0	6.0
RTB (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	6	2.7	2.5	1.9	1.0	6.0
Pine Beetles (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	0	n/a	n/a	n/a	n/a	n/a

<sup>a</sup> Refers to how many of four potential quadrants had severe bark char rating

<sup>b</sup> Refers only to #s of RTB and pine beetle pitchtubes for trees with beetle activity

### **Monitoring Large-Diameter Pines in additional 2008 Upper Cow Rx Fire Unit**

An area adjacent to the raking case study had Rx fire application in summer 2008 and was incorporated as a monitoring-only unit as no pre-burn or raking treatments occurred. This unit had spatially inter-mixed ponderosa and sugar pines majority of which exceeded 30" DBH. The unit was surveyed prior to beetle flight in April 2009 and trees had no RTB or pine beetle attacks. 168 ponderosa or sugar pines >30" DBH were established as monitoring trees and assessed for bark char severity and beetle activity one year post-burn in Fall 2009.

One year post-burning results are reported by species stratification (Tables 9 & 10). Interestingly, 45% of all sugar pines were attacked by RTB while only 18% of ponderosa pines had attacks even though trees species were spatially adjacent (Appendix C – Stem Map). Similarly, attack rates were higher as  $\approx 2$  times greater numbers of RTB-caused pitchtubes were found in attacked-sugar compared to ponderosa pines. No study tree mortality occurred one year post-burning in this monitoring unit.

**Table 9. Sugar pine characteristics one year post-burn in 2008 Rx fire monitoring unit**

Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem Diameter (in)	69	44.5	42.9	10.4	30.0	78.0
Quadrants w/ Severe Char <sup>a</sup> (#)	69	0.5	0.0	0.6	0.0	2.0
RTB (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	31	11.6	4.0	17.5	1.0	84.0
Pine Beetles (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	1	20.0	20.0	n/a	20.0	20.0

**Table 10. Ponderosa pine characteristics one year post-burn in 2008 Rx fire monitoring unit**

Variable	n	Mean	Median	Std Dev	Minimum	Maximum
Stem Diameter (in)	99	40.9	40.1	6.9	29.9	58.0
Quadrants w/ Severe Char <sup>a</sup> (#)	99	1.1	1.0	0.9	0.0	3.0
RTB (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	18	4.6	2.0	5.9	1.0	22.0
Pine Beetles (pitchtubes tree <sup>-1</sup> ) <sup>b</sup>	0	n/a	n/a	n/a	n/a	n/a

<sup>a</sup> Refers to how many of four potential quadrants had severe bark char rating

<sup>b</sup> Refers only to #s of RTB and pine beetle pitchtubes for trees with beetle activity

Trees in this monitoring unit were assessed two years post-burning in October 2010; however, only 50% were monitored due to funding limitations. In general, RTB attacks occurred almost exclusively in trees with 2009 RTB activity and attack rates were reduced 90% on average from 2009 to 2010. Mortality occurred in a 67" DBH sugar pine with  $\approx$  84 2009 RTB pitchtubes and likely MPB-attack.

### **Preliminary Conclusions**

Depth to mineral soil distributions immediately surrounding large-diameter study trees in Upper Cow units were high and maximum measurements per tree (Figure 3) often exceeded the forest floor fuel depth of 30 cm found by Nesmith et al. (2010) as a break-point for consideration of raking to reduce mortality in >20" DBH sugar pines.

Preliminary results from this case study indicate duff and litter raking may be an effective means to reduce 1) cambium injury (based on proxy of bark char severity) and 2) RTB attack in large-diameter pines exposed to Rx fire. Tree mortality was not observed in any raked or non-raked trees one year post-burning and we observed no evidence that raking treatments can directly cause tree mortality to-date.

Interestingly, duff/litter depths were found to be greatest in ponderosa compared to sugar pines in the rake-only and rake + Rx fire study units; however, the 2008 burn monitoring unit had  $\approx$  3 times as many sugar pines attacked by RTB compared to spatially inter-mixed ponderosa pines. This may be due to thinner bark and greater cambium injury and/or oleoresin exudation in sugar compared to ponderosa pines.

Study trees will be monitored until 2014 (5 years post-fire and raking) to assess further beetle activity, mortality rates, and raking efficacy in these units. A FHP report will be issued at following the final monitoring survey.

### **Acknowledgments**

We would like to thank a variety of individuals for their invaluable assistance with this case study including: the numerous volunteers of the Central Sierra Environmental Research Council for donating their time and effort to rake study trees; Summit Ranger District Fire and Fuels personnel for accommodating study trees within Rx burning units; Maria Benech for logistical support; Tashia Steele and Gracie Smith for assistance with data collection; and Danny Cluck for case study plan review.

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## Appendix A. Pertinent experimental research assessing bark beetle<sup>a</sup> activity in fire-injured trees

Location	Reps	Time Period	Beetle Species (Burn Treatment vs Non-Burned Units)	Study Findings	Literature cited
Northern CA - Lake Tahoe Basin	5	1997-1998	JPB in PIJE <sup>b</sup> (5 vs 1% of all host attacked); RTB (23 vs 0%); <i>Ips</i> (9 vs 0%)	1 year post-Rx burn: burn trees 24.8 times more likely attacked by JPB, <i>Ips</i> , and/or RTB than unburned; Significant JPB attack variables: % crown scorch, % live crown, bole char height, soil burn severity	Bradley and Tueller 2001
Teakettle Experimental Forest	9 <sup>c</sup>	2001-2004	MPB in PILA <sup>b</sup> (7-13 vs 2-3% treatment range for mean % of all host attacked); JPB (5-13 vs 2-6%); RTB (5-8 vs 1-3%), FEN (12-18 vs 3-12%)	3 year post-Rx burn bark beetle-attacks higher in burned units for JPB, MPB, FEN, RTB. Mortality skewed toward larger-diameter (>25 in. DBH) Jeffrey and sugar pines with basal fire-injury	Maloney et al. 2008
Blacks Mtn Experimental Forest	4 <sup>c</sup>	1999-2002	MPB in PIPO <sup>b</sup> (0.7 vs 0.2% of all host attacked); WPB (1% vs 0.1%); FEN (3 vs 1%); <i>Ips</i> (0.8 vs <0.1%); all beetles (2.6 vs 0.3%)	2 year post-Rx burn bark beetle-attacks higher in burned units for WPB, MPB, FEN, & <i>Ips</i> . Mortality was not skewed towards larger diameter trees but was skewed towards white fir (47.6% of all mortality).	Fettig et al. 2008
Central CA - Sequoia National Park	3	2002-2006	MPB/WPB/JPB in <i>Pinus</i> (0.45 spring burn and 0.49 fall burn vs 0.16 non-burned probability of beetle attack) FEN in <i>Abies</i> (0.26 & 0.12 vs 0.02)	3 year post-Rx burn attacks higher in burned units for MPB, WPB, and RTB. Given attack, mortality skewed toward smaller-diameter (<16 in. DBH) fir but not skewed in sugar pines. Burn season did not affect <i>Pinus</i> attacks & inconclusive for <i>Abies</i> .	Schwilk et al. 2006
Northern CA - Tahoe National Forest	3	2004-2008	Fire+bark beetles+other mortality agents (15% spring and 16% fall burn vs 0.3% non-burned total tree mortality)	3 year post-Rx Spring vs Fall burning had similar fire/bark beetle/other-caused tree mortality. WPB-caused greater large-diameter (>20 in. DBH) PIPO mortality in Spring [but not Fall] vs Non-burned units. Tree mortality (by all agents) skewed towards smaller (<8 in. DBH) trees.	Fettig et al. 2010b
Wildfires: McNally, Power, Cone, etc.	N/A <sup>f</sup>	2002-2009 <sup>g</sup>	Non-burned area not surveyed; 82% of post-wildfire PILA mortality in Power Fire was associated with MPB attack	5-year post-fire variables that influenced probability of mortality after wildfire varied by species and included: % live crown kill, DBH, cambium kill, presence of RTB attack ( <i>Pinus</i> only).	Hood et al. 2010
Southern Cascade Mtns., Klamath National Forest	3	2001-2005	MPB/WPB/ <i>Ips</i> spp. in <i>Pinus</i> and FEN in ABCO <sup>b</sup> (9 vs 3% bark beetle-caused tree mortality) <sup>h</sup>	4-year post-fire majority (≈74.9% of all trees, ≈58.6 of all pine, & ≈85.2% of all fir) of all bark beetle-caused tree mortality occurred in Rx burn (burn only & thin+burn) units. Tree mortality was skewed toward small diameter pine and fir.	Fettig et al. 2010a
AZ and NM - Four National Forests	4	2003-2006	<i>Dendroctonus</i> <sup>d</sup> & <i>Ips</i> spp. (13 vs 2% of all trees attacked); (8 vs 0.3% of all trees successfully attacked); (8.4 vs 0.6% total tree mortality)	3 year post-Rx burn attacks increased with crown damage. Mortality not skewed to certain DBH class. Best mortality predictors was crown scorch with bark beetle attack rating & bole char severity also significant.	Breece et al. 2008
Northern AZ	3	1995-1999	Non-burned area not surveyed; PIPO mortality likely at 70-80% crown damage w/ no insect attacks; RTB-attacked PIPO had 74%, 68%, & 48% survival rates 3 years post-burn	3 year post-Rx burn & wildfire variables that influenced PIPO probability of mortality (Pm) after wildfire: % crown damage (scorch+consumption) and <i>Dendroctonus/Ips</i> attack severity (none, partial, & mass-attacks).	McHugh et al. 2003
Northern Rocky Mnts - WY and MT	3 <sup>e</sup>	2001-2004	Non-burned area not surveyed; 95% of DFB attacks were in fire-injured trees	Variables that influenced DFB probability of attack: DBH, SDI, % live crown kill, & cambium necrosis. Excluding SDI, previous variables with beetle presence/absence were used to assess probability of mortality in fire-injured trees.	Hood and Bentz 2007

<sup>a</sup> Bark beetle acronyms: JPB = *Dendroctonus jeffreyi*; MPB = *D. ponderosae*; WPB = *D. brevicornis*; RTB = *D. valens*; DFB = *D. FEN* = *Scolytus ventralis*; *Ips* = *Ips* spp.

<sup>b</sup> Tree Species acronyms: PIJE = *Pinus jeffreyi*; PILA = *P. lambertiana*; PIPO = *P. ponderosa*; ABCO = *Abies concolor*; tree species not distinguished are specific to the attacking bark beetle in that region

<sup>c</sup> Reps refer to burn vs non-burn treatments; imbedded thinning treatments also exist

<sup>d</sup> > 80% of trees in study area were attacked by >1 species of bark beetles; *Dendroctonus* spp. included: WPB, RTB, *D. frontalis*, & *D. adjunctus*; *Ips* spp. included: *I. latidens*, *I. lecontei*, & *I. calligraphus*

<sup>e</sup> Three fires were surveyed with 79 plots

<sup>f</sup> Data from five fires collapsed to calculate probability of mortality for > 10,000 individual trees of various species

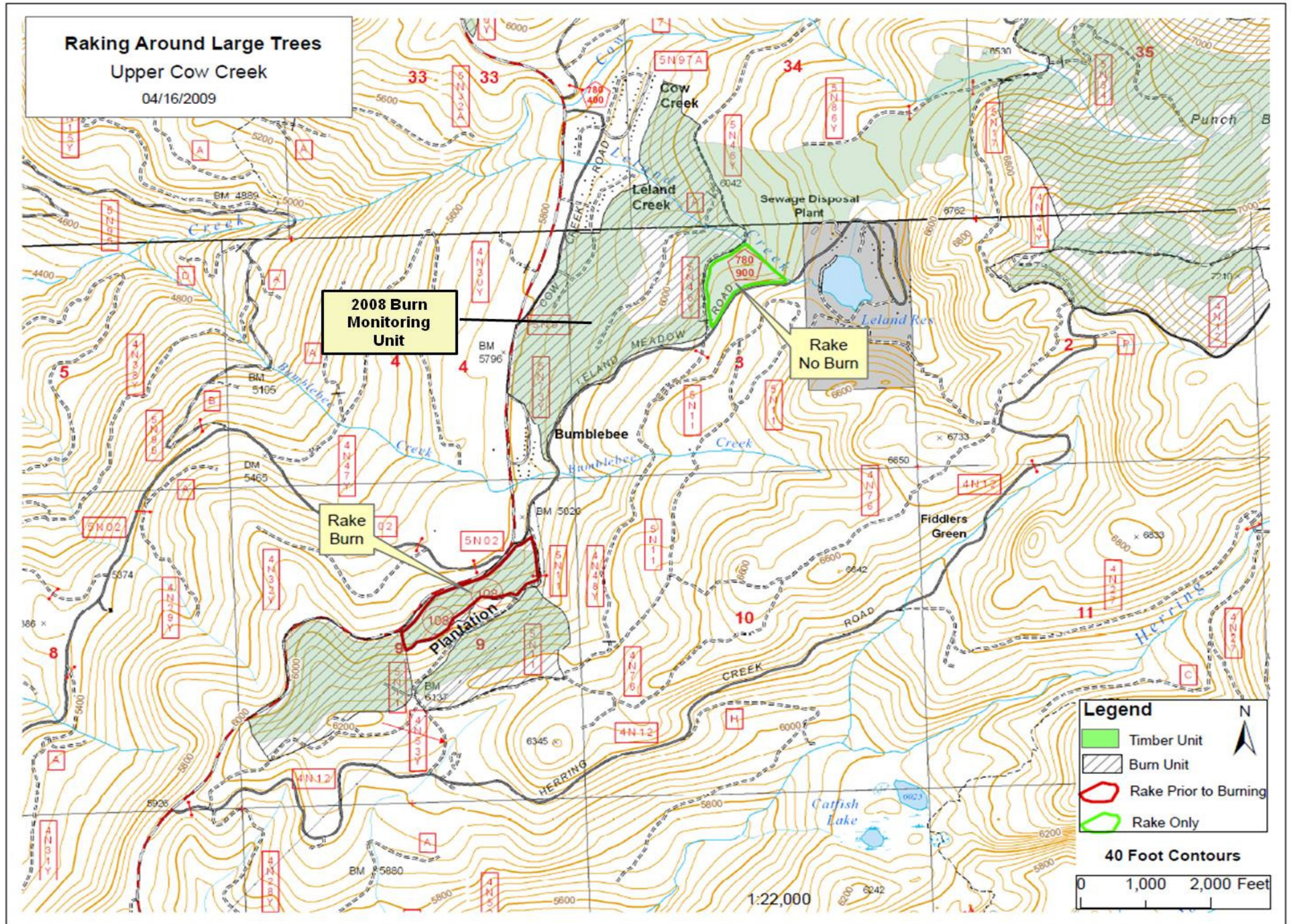
<sup>g</sup> Time period surveyed varied for each fire sampled

<sup>h</sup> Comparison refers to burn only unit vs control cumulative 4 years post-burn; Thin+burn unit (3.3% total bark beetle-caused tree mortality) did not differ from control; majority of mortality caused in MPB in PIPO

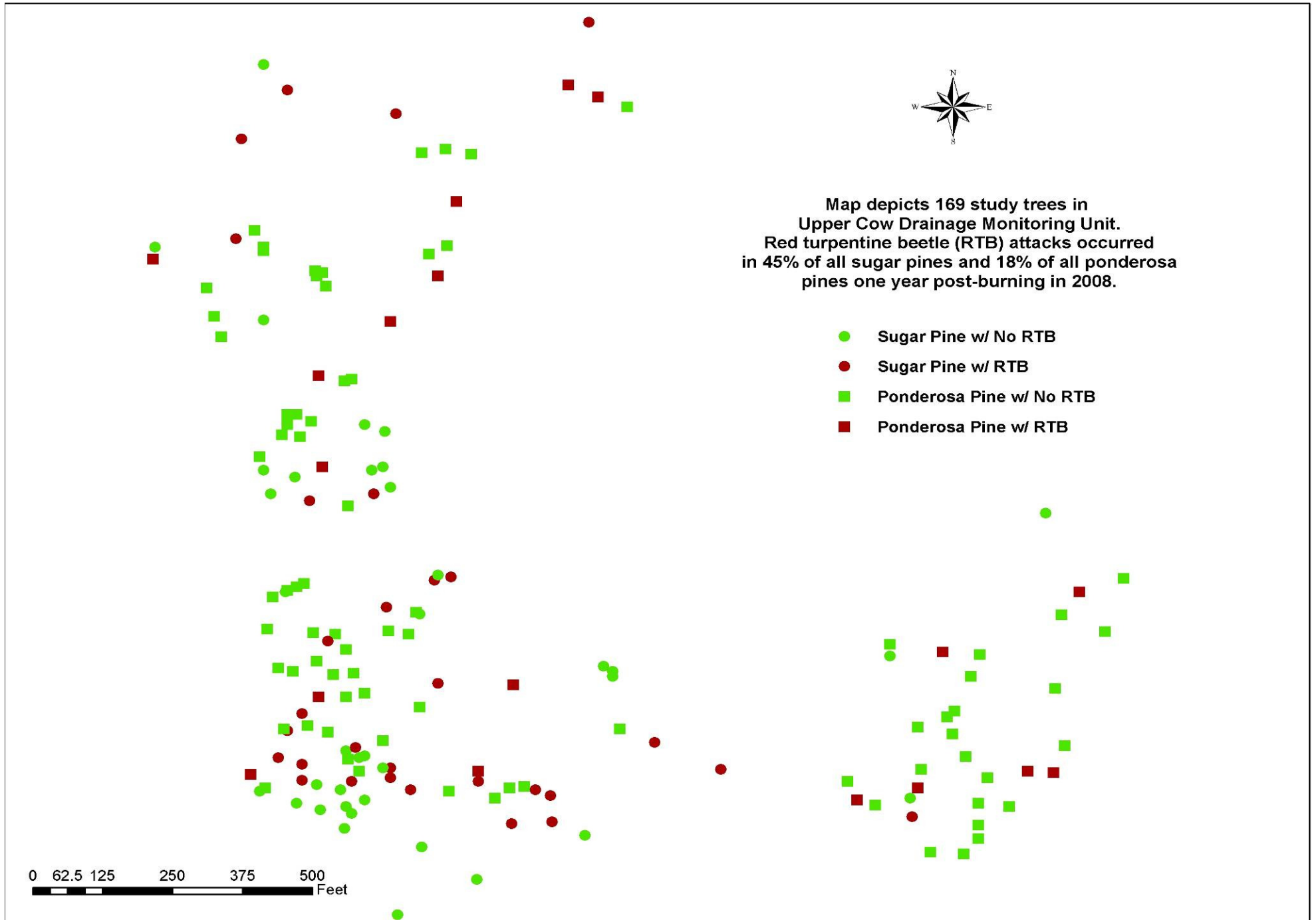
## **Appendix A. Research Citations for Bark Beetle Activity in Fire-Injured Articles**

- Bradley, T. and P. Tueller, 2001. Effects of fire on bark beetle presence on Jeffrey pine in the Lake Tahoe Basin. *Forest Ecology and Management*. 142, 205-214.
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- Fettig, C., Borys, R., McKelvey, S., Dabney, C. 2008. Blacks Mountain Experimental Forest: bark beetle responses to differences in forest structure and the application of prescribed fire in interior ponderosa pine. *Canadian Journal of Forest Research*. 38, 924-935.
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- Fettig, C.J., et. al. 2010b. Effects of prescribed fire and season of burn on direct and indirect levels of tree mortality in ponderosa and Jeffrey pine forests in California, USA. *Forest Ecology and Management* 260: 207-218.
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- Maloney, P., Smith, T., Jensen, C., Innes, J., Rizzo, D., North, M., 2008. Initial tree mortality and insect and pathogen response to fire and thinning restoration treatments in an old-growth mixed-conifer forest of the Sierra Nevada, California. *Canadian Journal of Forest Research*. 38, 3011-3020.
- McHugh, C., Kolb, T., Wilson, J. 2003. Bark Beetle Attacks on Ponderosa Pine Following Fire in Northern Arizona. *Environmental Entomology*. 32(3), 510-522.
- Shwilk, D., Knapp, E., Ferrenberg, S., Keeley, J., Caprio, A. 2006. Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest. *Forest Ecology and Management*. 232, 36-45.

# Appendix B – Map of Sample Tree Units Locations in Upper Cow Drainage, Summit Ranger District, Stanislaus National Forest



## Appendix C – Stem Map of 2008 Burn Unit Monitoring Study Trees by Species and Red Turpentine Beetle Attack Status



## **Appendix D. Case Study Plan**

### Collaborators

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John Nelson, NEPA Planner, Summit Ranger District, Stanislaus National Forest

Joel M Egan, Entomologist, South Sierra Shared Service Area, Forest Health Protection

### Objectives

- Pre-treatment objective: Assess whether DBH or species is associated with differing litter/duff depths
  - Assess unit strata and collapse if not significant then assess with Analysis of Covariance tables
    - Identify if DBH is correlated with average tree litter/duff depths
    - Identify if species is correlated with average tree litter/duff depth
- Pre-treatment objective: Assess whether uphill or downhill side of tree is associated with differing litter/duff depths
  - Collapse over unit and population strata
  - Compare paired observations averaged from 3 uphill vs 3 downhill measurements per tree for statistical difference
- Post-treatment objective: Determine if raking alone will directly cause of tree mortality
  - Compare population of raked vs unraked trees, by species, without exposure to fire with the following variables: bark beetle attack (*Dendroctonus valens*, *D. ponderosae*, *D. brevicomis*) & tree mortality
  - Summarize any differences in beetle attack rates and mortality of all raked trees
  - If mortality occurs review spatial distribution for switching mechanism effect
- Post-treatment objective: Determine if raking prior to prescribed burning reduces tree injury or mortality
  - Compare populations of raked vs unraked trees, by species, after exposure to Rx underburn with the following variables: bark char severity, bark beetle attack & tree mortality
  - Summarize differences in these variables for each population
  - Summarize any pre-burn data variables associated with beetle attack or tree mortality: duff/litter depth or spatial location

## Methods

*Study site:* As multiple factors can interact and contribute to tree mortality, the ideal monitoring site will have minimal inter-tree competition, similar topography and soil conditions throughout, an abundance of large diameter (> 30" DBH) trees of a given pine species, and similar duff/fuel loadings around tree boles to reduce the influence of confounding variables. A burned and no burned unit will be designated and should have similar characteristics (aspect, slope, topography, etc.) and be within a few miles spatial proximity of each other.

*Study populations:* Treatment populations will include: raked and non-burned, non-raked and non-burned, raked and burned, and non-raked and burned trees (Table 1). Each population will include at least 15 trees each for ponderosa (*Pinus ponderosa*) and sugar (*P. lambertiana*) pines. If the District wishes to monitor raking for other species present, each species will be treated as a separate population.

Table 1. Minimum Frequency of Trees Needed by Treatment for each Species

		<u>Burned</u>	
		Yes	No
<u>Raked</u>	Yes	15	15
	No	15	15

*Individual Tree Characteristics:* Trees in the study population will meet the following criteria: DBH >30", the pine species that is most abundant in the study site (ponderosa and sugar), full vigorous crowns, dominant or co-dominant canopy position. Trees that have the following will be included in a small, separate population of damaged trees: mechanical or other significant damage, cat-faces, disease infection, insect attack, close proximity (within dripline) to brush or other competing vegetation that would be difficult to remove.

*Pre-fire data collection and treatment assignment:* Trees will be selected in a burned and non-burned unit based on the above criteria. Each tree will be initially flagged and the following data will be taken:

- Tree identification assignment – tree number and UTM coordinate
- DBH to nearest tenth inch
- Crown dominance position
- Litter/duff depths - at cardinal directions respectively measure litter and duff depths at 0, 1, and 2 feet from tree base to the nearest tenth inch or centimeter.
- Disease (white pine blister rust) infection rates or any damage to trees

*Pre-fire comparison of treatment populations:* After initial data collection trees will be paired by spatial proximity to promote equal exposure to bark beetle populations, similar fuel depths and soil characteristics, etc. Each tree in a spatial pair will be assigned to be

raked or not raked. For each of the burned and non-burned units, data from populations of raked and non-raked trees will be statistically compared (Student's t-test or Wilcoxon signed-rank non-parametric equivalent) to ensure similar tree diameter, litter depth, and duff depth levels. Outliers will be identified as any data point 3 standard deviations from the mean. Should populations differ it will likely be due to skewed distributions or outliers. Outlier data points (for example extremely deep duff depths) will be removed from the sample populations but will still be paired (if possible), assigned a random raking treatment, and monitored. Should other/unknown factors contribute to population differences, the magnitude of these differences will be assessed for "reasonable biological significance" and trees maybe added or removed from populations to ensure comparability.

Forest Health Protection personnel will be responsible for tree identification, data collection/analysis, and population comparisons.

Completed: tree selection 5/1/09, data collection 5/15/09, population comparison completed on 9/15/09 and yielded no differences.

*Treatment implementation:* When similar populations of raked and non-raked trees are ensured, each tree will be tagged at DBH and those designated for treatment will be raked. Raking will remove all litter and duff (down to bare mineral soil) within a 2-foot radius around the base of each treated tree. Raked material will be dispersed evenly outside the 2-foot raked area to ensure no fuel buildup from the treatment.

District personnel & collaborators will be responsible for raking treatment implementation and underburning units.

Completed: Raked 5/15/09 & re-raked 10/13/09, Rx fire application 11/11/09

*Post-fire data collection:* Immediately following the prescribed underburn, after all duff smoldering and consumption has ceased, the following data will be taken from all sample trees: bark char severity rating, immediate bark beetle attack (beetle species and estimate of pitch tubes present), percent live crown scorch, and tree mortality occurrence.

Each Fall, preferably in October for five post-fire growing seasons, all sampled trees will be evaluated by taking the following data: percent live crown kill (1<sup>st</sup> year post-fire or Fall 2010 sampling), red turpentine beetle attack with count of pitch tubes present, western/mountain pine beetle attack with count of pitch tubes present, and live/fading/dead designation for each tree.

Forest Health Protection personnel will be responsible for all post-fire data collection.

*Analysis:* This monitoring is a case study and will not have any statistical replication of treatment populations. Thus, findings will be a case-study summary of mortality, bark beetle attack, and estimated cambium injury (with proxy of bark char severity) in raked and

non-raked trees. Pre-burn litter/duff depths and post-burn bark beetle presence will be compared in trees that lived/died to identify variables associated with mortality/damage.

Additional spatial and temporal replicates may be added if similar populations of large-diameter ponderosa or sugar pines are available in adjacent Forests.

#### Final Product

A Forest Health Protection service area report summarizing the monitoring with specific emphasis on answering questions posed in the stipulated objectives.